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Polarization properties of 6.7 GHz methanol masers in NGC6334F

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Abstract. The Australia Telescope Compact Array (ATCA) has been used to make the first full polarization observations of 6.7 GHz methanol masers. Linear polarization was detected towards all four sources observed, at levels between a few and 10%, while none of the sources show circular polarization stronger than approximately 1.5%. Linear polarization appears to be more common in the 6.7 GHz methanol maser transition than it is for the 12.2 GHz transition, consistent with the hypothesis that the 6.7 GHz masers are more saturated.

1. Introduction

Masers from the 6.7 GHz transition of methanol were first detected towards star formation regions by Menten (1991). The 6.7 GHz transition is the strongest of the class II methanol masers and has been detected towards more than 400 sources.

One aspect of class II methanol masers which has received relatively little attention to date has been the polarization properties. The polarization properties of masers are strongly influenced by the magnetic properties of the molecule producing the emission. OH is a paramagnetic molecule and frequently exhibits very high levels of circular polarization. Water is a diamagnetic molecule and consequently has a much smaller magnetic dipole moment, typically water masers show modest levels of linear polarization, but no circular polarization. Methanol is also a diamagnetic molecule and so it is expected to have polarization characteristics similar to water masers. Koo *et al.* (1988) made a single dish study of the polarization of five 12.2 GHz methanol masers. They detected no linear polarization stronger than 3% towards three of these (G188.94+0.89, Cep A & NGC 7538), linear polarization of a few percent towards W3(OH) and 6-10% towards NGC6334F. The observations reported here are the first detailed studies of the polarization properties of 6.7 GHz methanol masers.

2. Observations

The observations were made on 1999 September 22 and 25 using the ATCA in the 6A configuration, which yields maximum and minimum baseline lengths of 337 m and 5939 m respectively. The ATCA has linearly polarized feeds and the correlator was configured to record a 4 MHz bandwidth with 1024

spectral channels for each of the products XX, YY, XY and YX on all baselines. This resulting velocity resolution was approximately 0.21 km s^{-1} . Four strong 6.7 GHz methanol maser sources were observed, G339.88-1.26, G345.01+1.79, NGC6334F and G9.62+0.20. Five minute scans on each being interleaved with one minute scans on nearby phase calibrator sources. In order to obtain good parallactic angle coverage additional scans were scheduled during transit for each source. Bandpass and primary flux calibration was obtained through a 30 minute observation of PKS1934-638 on each of the two days of observations.

The data were processed using the *miriad* software package using standard procedures for ATCA observations. The data for each of the two days were edited and calibrated independently and the results compared to check for consistency prior to averaging. In the absence of any systematic errors in the data or calibration, the accuracy to which polarization can be measured with the ATCA is determined by the signal to noise ratio in the observations used to determine the leakage terms. For these observations a 30 minute scan on PKS1934-638 was used to determine the antenna bandpasses and polarization leakage corrections. After averaging all baselines together, the signal to noise ratio for the PKS1934-638 observation was estimated to be approximately 200:1, suggesting that the accuracy of the polarization measurements should be 0.4%.

3. Results

Linear polarization was detected at levels between a few and 10% in a number of spectral components, in each of the primary target sources. Most components exhibit linear polarization at a level of about 5% or less, although some features have no linear polarization (within the observational limits). For example in NGC6334F there are number of maser components in the velocity range of $-10.0 - -6.5 \text{ km s}^{-1}$ with peak flux densities greater than 50 Jy, which show no linear polarization stronger than 0.4%. The rest of this paper will discuss only the results for NGC6334F, the results for other sources can be found in (Ellingsen 2002).

Koo *et al.* (1988) detected linear polarization in two 12.2 GHz methanol masers, W3(OH) and NGC6334F. Only the latter of these is within the declination range covered by the ATCA and so it is the only source for which we are able to make a comparison of the polarization properties of the two transitions. The first high-resolution observations of the 12.2 GHz methanol masers in NGC6334F, made with the Parkes-Tidbinbilla Interferometer (PTI) by Norris *et al.* (1988) found that the emission arises from two clusters which are separated by approximately $3''$ (i.e. not resolved by the $4'$ beam used by Koo *et al.* in their observations). One of these clusters is projected on the leading edge of the HII region NGC6334F, while there is no radio continuum emission stronger than a 5σ limit of 4.8 mJy at the location of the other (Ellingsen, Norris & McCulloch 1996). Subsequent VLBI observations by Ellingsen *et al.* (1996) found that at 12.2 GHz the emission at velocities less than -11.0 km s^{-1} is primarily located in the offset cluster (hereafter NGC6334F(NW)), while the emission at velocities greater than -11.0 km s^{-1} is located in NGC6334F. This suggests that there should be relatively little blending of emission between the two clusters which would confuse the position angles reported by Koo *et al.* (1988)

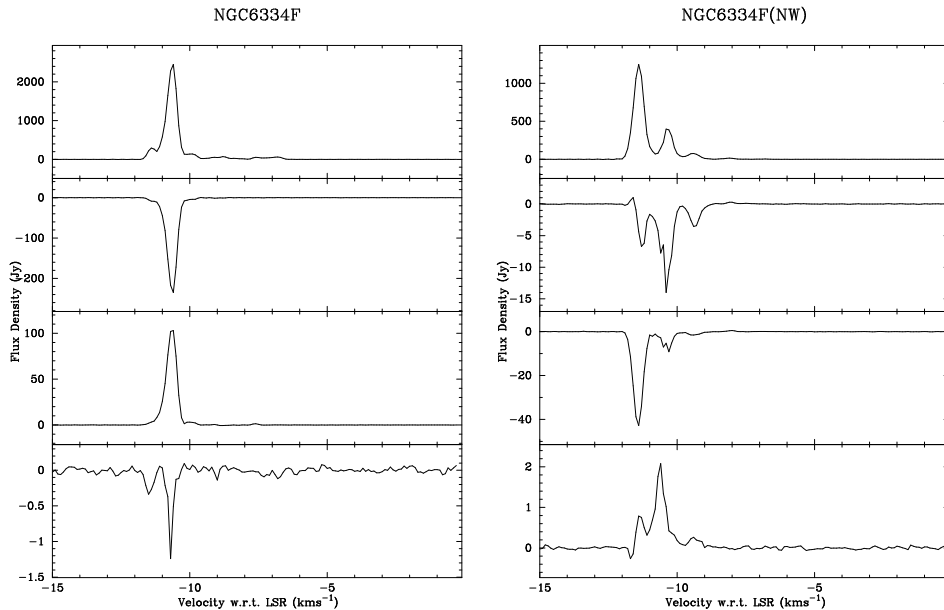


Figure 1. The spectrum of the 6.7 GHz methanol maser emission in NGC6334F and NGC6334F(NW) in each of the four stokes parameters I, Q, U and V (from top to bottom in that order)

The first high resolution observations of the 6.7 GHz methanol masers in NGC6334F were made by Norris *et al.* (1993). At 6.7 GHz the velocity ranges for the three clusters overlap significantly. Spectra for each of the four stokes parameters in each cluster were obtained from cleaned (but not self-calibrated) image cubes, and are shown in Fig. 1. It is apparent from Fig. 1 that many of the maser components in both clusters are significantly linearly polarized. The strongest features in each of the stokes V spectra are 0.05% and 1.4% of the total intensity at the same velocity for NGC6334F and NGC6334F(NW) respectively. The latter of these is marginally significant and further investigations are being undertaken to determine if it is real.

Fig. 2 shows the linear polarization spectrum of the emission from the two main clusters of 6.7 GHz methanol masers. In the NGC6334F central cluster the emission with the highest degree of polarization (10.5%) at -10.6 km s^{-1} corresponds to the strongest feature in the total intensity spectrum. Interestingly the highest degree of linear polarization at 12.2 GHz is also 10% at -10.6 km s^{-1} and the VLBI observations show that the emission from the two transitions at this velocity is coincident (Ellingsen *et al.* 1996). The position angle of the emission at 12.2 GHz is quoted by Koo *et al.* as 45° , while at 6.7 GHz it is 78° . For the NGC6334F(NW) cluster the strongest component (at -11.4 km s^{-1}) also shows the greatest degree of linear polarization, although in this case it is lower (3.5%) than the degree of polarization of the corresponding 12.2 GHz emission (6%). The position angle at 12.2 GHz is 90° , while at 6.7 GHz it is -48° . Since we only have measurements at two frequencies it isn't possible to determine unambiguously the Faraday rotation toward the masing regions.

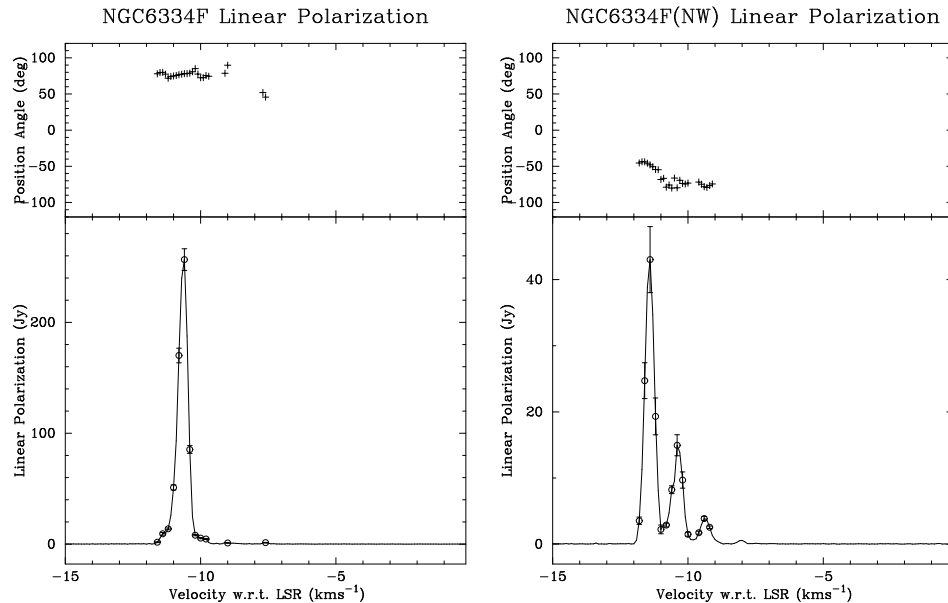


Figure 2. The linear polarization spectrum of NGC6334F (left) and NGC6334F(NW) (right)

4. Conclusions

Modest levels of linear polarization are relatively common towards strong 6.7 GHz methanol masers. Comparison of the polarization properties between the 6.7 and 12.2 GHz transition in one source (NGC6334F) shows that for this case they are strikingly similar. This suggests that high spatial resolution polarization observations of the two transitions may allow the determination of the intrinsic position angle of the polarized emission, which in turn could be used to obtain information on the line of sight magnetic field in these regions.

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